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Completion and Field Demonstration of a Portable Coastal Observatory
http://woodshole.er.usgs.gov/operations/coastobs/

Daniel E. Frye
Woods Hole Oceanographic Institution
Phone: 508-289-2759; email: dfrye@whoi.edu

Bradford Butman
U.S. Geological Survey
Phone: 508-457-2212; email: bbutman@usgs.gov

ABSTRACT

The goal of the NOPP funded project, Low Cost Modular Telemetry for Coastal Time Series Data [1], was to develop an affordable, easy to use technology for the real time collection and dissemination of data from instruments deployed in the coastal ocean. The observing system that was developed consists of four elements: 1) low cost acoustic modems that are deployed with each instrument, 2) small, easy to deploy surface buoys (and moorings) that carry the acoustic hydrophones and acoustic receiver and RF link, 3) a shore-based receive station that automatically forwards data received and logs it on a website, and (4) a back channel to the surface buoys from the laboratory so that acoustic receivers and RF links can be modified without requiring a site visit. An alternative to (2) was to deploy systems on existing Coast Guard buoys; if successful, this strategy might provide a large network of stations, especially in high-traffic areas where locating additional buoys are not feasible.

The goal of the continuation project reported on here, Completion and Field Demonstration of a Portable Coastal Observatory, was to complete the development and testing of the low cost acoustic modem, which was not completed under the original project and to demonstrate its performance in the field. The larger goal was to demonstrate a technological approach for building coastal observatories with real time data distribution. Our vision is that acoustically linked coastal observatories will provide easy to use and easy to relocate systems that compliment fixed cabled observatories, which provide high bandwidth and power to offshore sensors, but are expensive, difficult to install and not relocatable.

INTRODUCTION

The initial phase of this project developed the Portable Coastal Observatory concept (Figure 1) and deployed a small, low-cost buoy in Massachusetts Bay over a period of more than a year to test the acoustic and RF links that are integral to the concept. These tests successfully demonstrated the reliability and robustness of the

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Daniel E. Frye
Bradford Butman

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Applied Ocean and Physics and Engineering Dept.
Woods Hole Oceanographic Institution
86 Water St., MS #18
Woods Hole, MA 02543

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					(508) 289-2759

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surface buoys and their moorings and the effectiveness of the line of sight radio modems. The acoustic links (operated with a previous version of the acoustic modem, the Utility Acoustic Modem or UAM [2]), however, experienced higher error rates than anticipated and the system installed on a buoy of opportunity, a Coast Guard Buoy located outside Boston Harbor, functioned poorly due to high noise levels generated by the buoy and to acoustic interactions with the buoy hull.

The second phase of the project was funded to solve the acoustic communication problem and complete the field testing of the new generation acoustic modems under a variety of environmental conditions. We also wanted to investigate alternative methods for utilizing buoys of opportunity and to complete the web-based data collection and dissemination system. Funding was provided by the NOPP program and the project was conducted cooperatively with the U.S. Geological Survey, Woods Hole Oceanographic Institution, RD Instruments, Inc., the Massachusetts Water Resources Authority, and the U.S. Coast Guard.

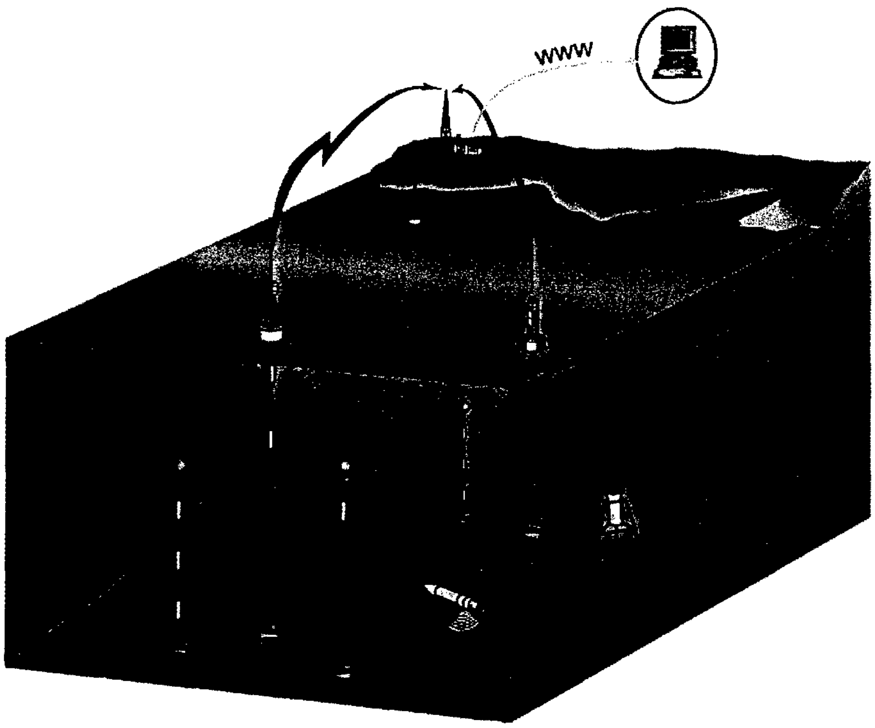

Figure 1
Conceptual drawing of the Portable Coastal Observatory illustrating the acoustic and RF data links from sea to shore and the final connection to the web.

RESEARCH PROPOSAL SUBMITTED TO

Applied Research Laboratory
The Pennsylvania State University
North Atherton Street
State College, PA 16801

by

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
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PLUSNET ACOUSTIC COMMUNICATIONS

1. Principal Investigator(s):

PII Redacted

Dr. James C. Preisig
Assistant Scientist
Applied Ocean Physics & Engineering Department
[redacted] Ph.D. 1992

Mr. Lee E. Freitag
Senior Engineer
Applied Ocean Physics & Engineering Department
[redacted] M.S. 1987

2. New Proposal:

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3. Endorsements:

Dr. James C. Preisig, Co-Principal Investigator
Applied Ocean Physics and Engineering Department
Tel: (508) 289-2736
Fax: (508) 457-2195
jpreisig@whoi.edu

Mr. Lee E. Freitag, Co-Principal Investigator
Applied Ocean Physics and Engineering Department
Tel: (508) 289-3285
Fax: (508) 457-2195
lfreitag@whoi.edu

Dr. W. Rockwell Geyer, Chair
Applied Ocean Physics and Engineering Department
Tel: (508) 289-2283
Fax: (508) 457-2194
aope-chair@whoi.edu

Mr. Maurice J. Tavares
Manager of Grant and Contract Services
Tel: (508) 289-2462
Fax: (508) 457-2189
mtavares@whoi.edu

Dr. James R. Luyten
Executive Vice President and Director of Research
Tel: (508) 289-2515
Fax: (508) 457-2189
jluyten@whoi.edu

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TECHNICAL APPROACH

The data telemetry and delivery concept that was developed can be thought of as a Portable Coastal Observatory. The approach provides a cost effective means to monitor the coastal ocean on a variety of space and time scales and distribute the data collected over the web in near real time. Low cost acoustic links are used to connect sensors to surface buoys that are equipped with radio links that transfer the data to shore. This approach avoids the need to lay fixed cables on the seabed to get real-time data and has the added feature that the sensors and RF buoys are easily moved to new locations. The receive system, located in the surface buoy, is capable of collecting and forwarding data from many independent sensors within the acoustic network. When the data is received by the radio link on shore, it is immediately forwarded to a website from a computer at the receiving station. Satellite RF techniques can also be employed on the surface buoys to eliminate the need to maintain a local shore station or to provide connection to buoys far from shore. We used Iridium on the Coast Guard buoy during the second phase of the project to demonstrate this capability.

The small, low cost acoustic modems used for the Portable Coastal Observatory were developed at WHOI by Johnson and Freitag [3] and were configured on this project for the shallow water application using a frequency hopping FSK (frequency shift keyed) modulation technique. The modems are a single small board measuring about 2 by 4 inches in size with a separate power amplifier board that is about 4 inches by 4 inches. They are frequency agile and can be operated over a frequency range from 10 to 30 kHz and can be programmed to send and receive using FSK or PSK (phase shift keyed) modulation. For the shallow water application they were programmed to transmit 160 bps (bits/second), which resulted in a net throughput of 80 bps after error correction coding. In other applications they have been used at throughput rates up to 5000 bps [4]. Transmit power was set to 8 Watts. The transmitters utilize a piezoceramic ring to attain an omnidirectional output signal. The receive modems on the surface buoys, which were UAMs, utilized two acoustic hydrophones to provide spatial diversity. By using two receive hydrophones, the system error rate was reduced from about 5% of packets with errors (with a single hydrophone) to less than 0.2% over a broad range of environmental conditions.

Figure 2 shows the simple buoy and mooring system used for the Portable Coastal Observatory. The dual hydrophone cage was suspended beneath the small (400 pounds of buoyancy) surface buoy at mid-water depth (14m in 25m of water) and wired back to the buoy through a short E/M cable and a molded chain with the electrical conductors helixed around its outer diameter. The molded chain is a key technology in making the mooring system reliable over several years of operation. Inside the surface buoy was an alkaline battery, a UAM receiver and a Freewave RF modem. In some deployments we substituted an Iridium modem for the Freewave unit to demonstrate a design that is independent of nearby shore stations. A small tower completed the buoy structure and it supported an antenna, Argos transmitter, light and radar reflector.

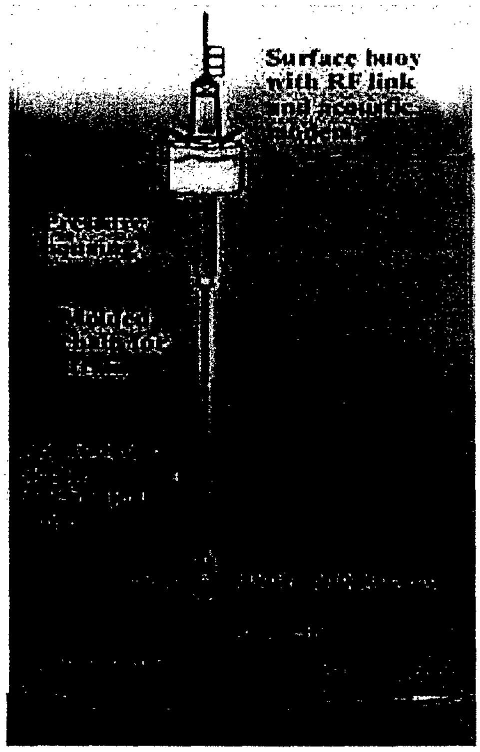

Figure 2
The surface buoy and mooring used in Mass Bay as part of the Portable Coastal Observatory system.

The buoy and mooring systems are small enough and light enough that they can be deployed from a small boat without lifting equipment. A 250-pound Dormoor anchor was used with a mooring scope of 1.5 to 1.0 and was reliable for a year deployment period without servicing. The acoustic transmitters were deployed on ADCP instruments deployed as part of the USGS array that is maintained in Massachusetts Bay as part of a system for monitoring the MWRA outfall and Cape Cod Bay (5). Deployments were conducted using chartered fishing boats as well as Coast Guard vessels that serviced the Boston B buoy on an annual basis.

RESULTS

Two sites were instrumented with ADCPs (provided by RD Instruments) mounted on a tripod frame on the sea floor. The ADCPs were interfaced to acoustic modems and configured to transmit hourly current profiles. A small surface buoy and mooring was designed and two systems were fabricated for use at the Scituate site in Massachusetts Bay (Fig. 3). The surface buoy and mooring is small and easy to deploy and has proven to be quite robust. It was deployed for about 2 1/2 years at Scituate without any mooring failures.

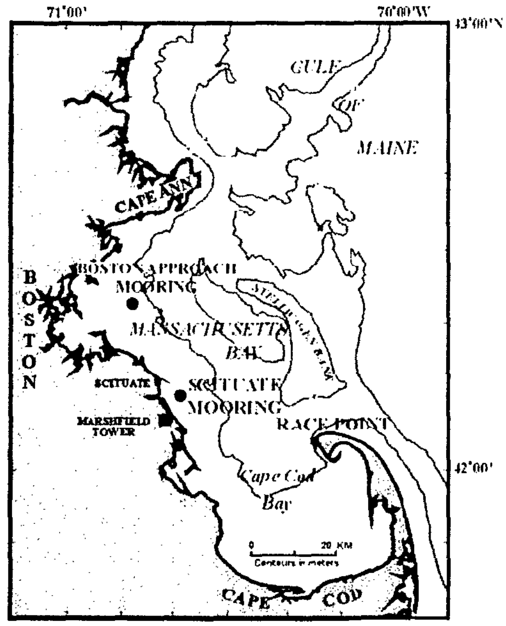

Figure 3
Location of the Scituate mooring site and the Boston B buoy site in Massachusetts Bay. The shore RF station is located at the Marshfield Tower.

Surface buoy electronics were installed on both the small buoy at Scituate and the Boston B Coast Guard navigation buoy. The surface package consisted of a UAM interfaced directly to a Freewave RF modem and an alkaline battery. At the Scituate site, the system worked reliably for most of its deployment life, forwarding hourly ADCP profiles to shore and from there to the website. The acoustic link initially exhibited high packet error rates (see Fig. 4); the system was modified on several occasions to improve performance. The final configuration used dual receive hydrophones and operated in the 15-22 kHz frequency band. When these modifications were implemented (see period after June 2001 in Fig. 4), the acoustic performance improved substantially to about 99.8%. (Note that a packet is 32 bytes of data). The additional reduction in error rate after October 2001 was a result of repositioning the transmit hydrophone above the tripod frame so that there was an unobstructed acoustic path to the surface buoy.

The Boston B buoy installation never worked well due noise generated by the steel buoy and its interactions with the waves and because the buoy mooring configuration did allow us to position the hydrophones well below the buoy hull. On the Coast Guard buoy the hydrophones were deployed at about 3 m depth in a molded hose that hung over the side of the buoy; the keel on the buoy extended below 3m and sometimes blocked the acoustic path to the instruments on the seafloor.

Range tests were performed in Mass Bay near the Boston B buoy to get a better idea of the acoustic footprint that can be supported with this design. Figure 5 shows the results of these tests, which indicates that ranges of only about 350m could be achieved with very low error rates. Errors seen at longer ranges were due to multipath interactions rather than signal strength. There was plenty of signal to decode correctly at 1 Km, but the frequency hopped FSK technique was only designed for about 40 msec signal spreading, while we observed spreading up to 250 msec at 1 Km. It should be noted that we have seen ranges a long as 10 Km using this same equipment in Monterey Bay where the acoustic path was less difficult.

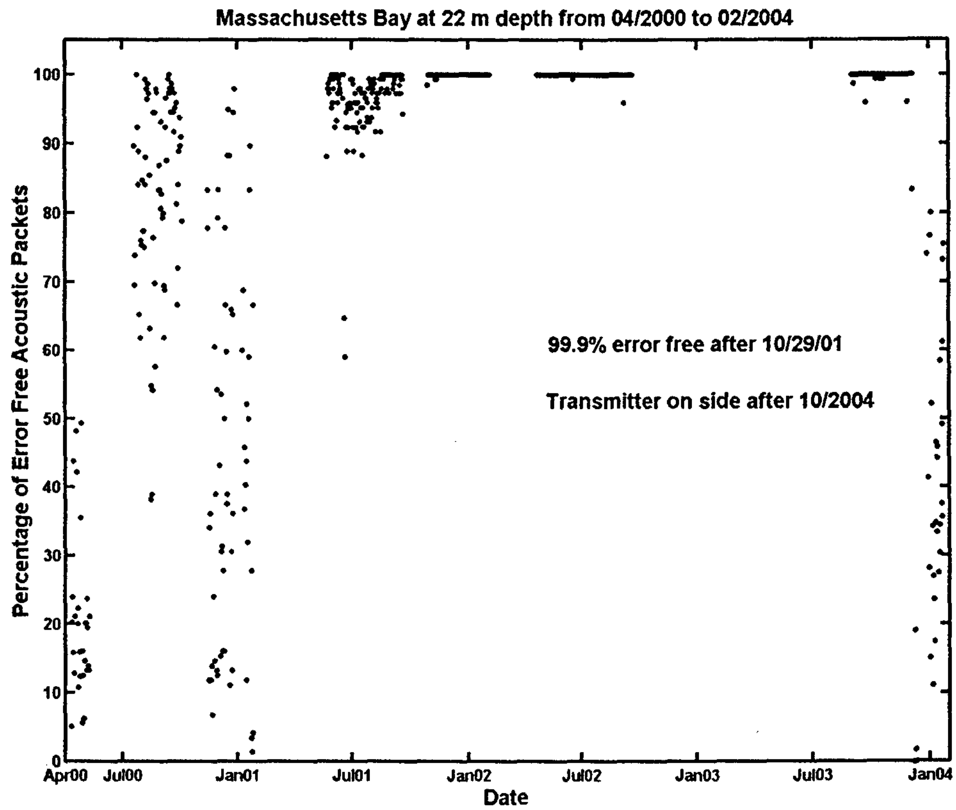

Figure 4
The percentage of packets received without errors as a function of time. One hundred and forty four 32 byte packets were transmitted each day.

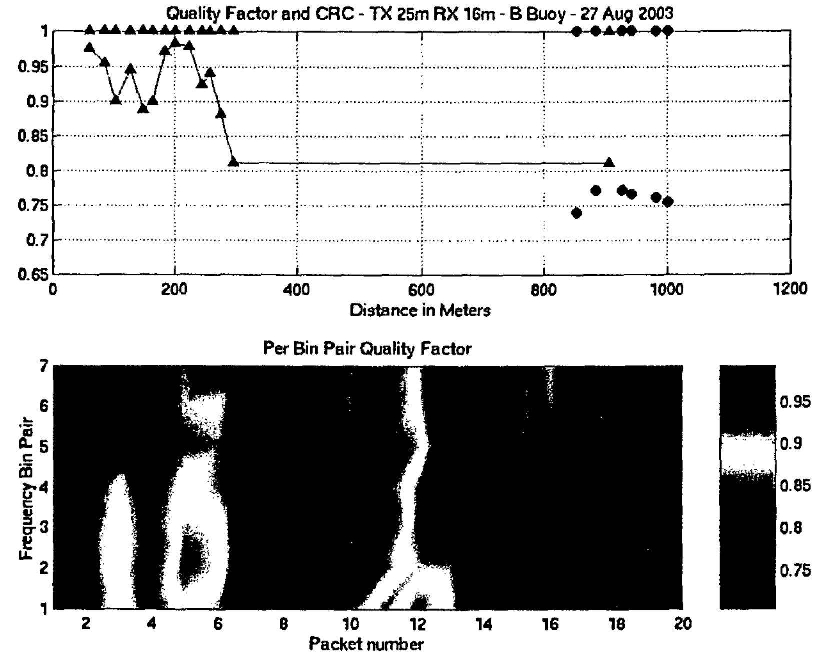

Figure 5. Results of range tests performed in Mass Bay showing excellent performance out to 350m range, but less than perfect performance at 850 to 1000m range. The red circles indicate one or more errors in the data decoding, blue triangles show a decoding quality factor. A value less than 0.8 indicates that the error correction coding may have difficulty correcting an error.

CONCLUSIONS

- The acoustically linked Portable Coastal Observatory concept has been demonstrated in prototype form in Massachusetts Bay. The moored surface buoy and other hardware have proven to be robust, low cost and easy to use.
- Design and implementation of the new generation small acoustic modem required more time than expected. However, once the new hardware was available it proved to be very reliable with almost negligible error rates using the latest modulation scheme with diversity-two reception.
- The telemetry system on the stand-alone research buoy at the Scituate site operated reliably for several years, but the system designed for the USCG Boston B Buoy did not operate well due to acoustic noise generated by the steel buoy and its interaction with the waves. The limited depth of the hydrophones suspended from the buoy, which prevented a direct acoustic path to the seafloor sensors, was also a factor.
- Servicing of the hardware on the USCG buoy required very calm sea conditions and was a severe operational constraint to utilizing these buoys for telemetry.
- An Iridium RF link replaced the Freewave system on the Boston B buoy worked quite well.

- The goal of demonstrating the Portable Coastal Observatory using multiple instruments was not accomplished on this project due to time constraints, but this feature of the acoustic network has recently been demonstrated on two NSF funded projects [4 and 5]. In these projects as many as 8 separate instruments have been deployed in the acoustic network.
- A real-time data processing and display capability has been developed and is available via the project web site.

We have developed and demonstrated a reliable and easy to use infrastructure for a Portable Coastal Observatory. The low-cost acoustic link works very reliably at modest data rates (160 bps uncoded, 80 bps coded) with almost no errors. The small coastal buoy systems are reliable, easy to maintain and relatively inexpensive. The RF links are commercially available and work well in the marine environment and an Iridium version has been demonstrated that allows the system to be independent of nearby shore stations. The acoustic system used in the shallow waters of Mass Bay has a limited range due to multipath spread. At present, this range is of the order of 400m using the frequency hopped FSK modulation method. Additional range is certainly possible at the power levels that were used, but will require additional investigation to verify. The Boston B buoy system did not work well, primarily because of noise associated with the large steel hull; the concept of using buoys of opportunity may not be viable with these Coast Guard buoys. The web-based data distribution system is operational. Various elements of the system are being used by other projects and other researchers because they have proven to be reliable and inexpensive. These other projects include:

1. Northern Gulf of Mexico Littoral Initiative- two acoustically linked buoy systems were deployed in the Gulf of Mexico for NAVOCEANO [7].

2. Short term deployments of the small coastal buoys using the designs developed under this project have been made at a number of sites including Bermuda, Monterey Bay, the Hudson River estuary, and an array presently deployed in Cape Cod Bay and Mass Bay as part of a Right Whale detection system.

3. ULTRAMOOR [6]- a new long term mooring design is deployed offshore of Greenland and uses the acoustic modems used for the NOPP funded work, but configured using PSK modulation in deep water. On this project the data rate is 1300 bps and the modems operate as both transmitters and receivers.

4. A deepwater Acoustically Linked Ocean Observatory [4] uses this technology to collect large quantities of data from several seafloor sensors and transmits it to shore using an Iridium link. It is a large, deepwater version of the Portable Coastal Observatory, but uses many of the same concepts. This system is presently deployed offshore British Columbia in 2500m of water.

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